Systemic risks caused by worldwide simultaneous bad and good harvest in agricultural market and trade under future climate change: stochastic simulation by the computable general equilibrium model

Yoji Kunimitsu, Gen Sakurai (National Agriculture and Food Research Organization)

Abstract

Extreme fluctuations of food prices in the global market, caused by the global synchronized production shocks due to climate change, may decrease the stability of food supply source portfolio through agricultural trade, like systemic risks in financial markets. This study aims to quantify the degree of systemic risk in the agricultural markets under future climate change and evaluate the effects of trade liberalization when systemic risk exists. Simulation analysis, using computable general equilibrium (CGE) model based on harvest predictions from crop model and global climate model (GCM), suggests the following. (1) In rice, which has the largest synergistic effect of output fluctuation, the output synergy was significant in combinations of trading countries with more than 40%. (2) This synchronicity of yields increases fluctuations in agricultural production and agricultural price by 22% and 84%, respectively. (3) Although trade liberalization can alleviate the vulnerability of agricultural production under climate change, in countries with large imports of agricultural products, such mitigation effect on price fluctuation by trade liberalization declines due to systemic risk. Therefore, by taking into accounts the systemic risk under future climate change, it is necessary to examine the true effects of agricultural trade policies and prepare countermeasures in advance.

Keywords: Global synchronized production shocks, synchronicity of yield fluctuation, mitigation effect by trade liberalization, global climate model (GCM), crop model

1. Introduction

Agricultural production is directly influenced by future climate change. A special report from the

IPCC reports that due to future climate change, the global average agricultural price in 2050 will rise by 23% compared to the present, combined with a decline in agricultural production and an increase in the world population. Such market disruption through the agricultural sector is a risk to the global economy. It is an important academic and policy issue how much the risk will change due to future climate change, and how much the liberalization of agricultural trade that can be considered as a means to mitigate the disturbance will be effective.

As a previous study, Tanaka and Hose (2011) examined the impact of productivity shock and the effect of trade liberalization due to climate change in the rice market by Monte Carlo simulation analysis using a global CGE model. According to their results, Japan's rice imports increased due to trade liberalization, but the decline in rice prices raised the level of public welfare and reduced the impact of productivity fluctuations in Japan. In addition, trade liberalization has no effects in which the fluctuation of Japanese market will be expanded, in response to fluctuations in productivity overseas. Therefore, they conclude that the liberalization of agricultural trade does not reduce Japan's food security level.

Their conclusions are consistent with portfolio theory that the overall fluctuation can be reduced by combining products with independent price fluctuations. However, their study did not analyze the impacts of correlated shocks among major grains and among countries as well. In this study, such influences caused by the shocks that correlate among crops and countries are called "systemic risk" according to financial engineering or computational finance. In other words, risk hedging to mitigate future price fluctuations is possible by combining stocks whose prices fluctuate independently, but if there is a correlation with the fluctuations in the combined stocks, a combined stock in the basket may crash. Systemic risk is the risk that a crash of one brand in the basket induces a crash of another brand like a domino. If climate change causes a correlation among crops or among producing countries, the liberalization of agricultural trade may not necessarily be effective as a risk hedging tool for climate change.

The purpose of this study is to confirm whether there is a systemic risk that changes in yield of agricultural products due to future climate change will affect the price of agricultural products in the world, and if there is such systemic risk, it is to quantitatively evaluate how much the impact is.

In the analysis, for the four main crops, the interrelationship of the crop yield fluctuations under future climate change among countries and among crops is identified by the yield prediction results of each country in the crop model. Then, the fluctuations in agricultural prices are calculated by inputting crop model's results into worldwide CGE model, and these results are compared with the no correlation case, in which crop yield fluctuations among countries and crops do not exist, quantified by Monte Carlo simulation analysis similar to Tanaka and Hosoe (2011).

The rest of this paper is organized as follows. Section 2 explains methods of analyzing the possibility of systemic risk by using annual and country-specific yield prediction of the four target crops, and quantifying the magnitude of systemic risk in agricultural production by the worldwide CGE model. Section 3 shows the possibility of systemic risk in global agricultural price fluctuations, and shows the impacts of systemic risk of future climate change on agricultural price fluctuations under the liberalization of agricultural trade. The final section 5 summarizes the results of the analysis and concludes with policy implications.

2. Methdology

2.1 Analytical data and methods for systemic risk in the global agricultural market

The systemic risk we focus on in this paper refers to the risk of simultaneous global failure or global harvests due to the correlation between annual yield fluctuations in different crops and countries of the world. In general, the effects of climate change on agricultural production appear as bad crops or good harvests due to changes in temperature and rainfall. For this reason, if climate change in the world's major agricultural countries is correlated, there is a high possibility that the world food market would simultaneously have bad harvest or rich harvest. Of course, it can be assumed that the impact of climate change appears not only as a yield but also as a change in the quality of agricultural products. Nevertheless, quantitative changes are more important in terms of securing food, so quality changes are not dealt with in this study.

The analysis uses 4 crop yield data over 3 periods. That is, the FAO's yield data for four crops in each country (1961-2014) and the forecasted yield for two periods in the future climate change (2015-2050 and 2051-2100) are used. Forecasted yield data for 2015-50 and 2051-2100 are the results of the crop model developed by Sakurai et al. (2016). For inputs of their crop model, the climate forecasts by five types of global climate models (GCMs) that have been opened and used in the 5th report of the IPCC are used. Table 1 shows the outline of GCMs used. The crop model formulates the relationship between yield and annual climatic conditions (daily temperature, solar radiation, precipitation). Specifically, crop growth and reproduction processes are formulated based on biological knowledge and field survey results, and parameters that are not available for field survey are estimated by Bayesian method from actual yield data and climate data. Therefore, the crop model used is a hybrid model of a pure process model and a statistical model.

The analyzed area is a total of 38 countries / regions, including 29 countries that are major producers and importers of 4 crops, and 9 regions that have been integrated in consideration of geographical proximity (Table 2). For the sake of simplicity, the country / region will be simply referred to as a country hereinafter.

Table 1. Overview of GCMs used

No.	GCMs	Institutions developing the model
1	GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory
2	HadGEM2-ES	Met Office Hadley Centre and Instituto Nacional de Pesquisas Espaciais
3	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
4	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
5	NorESM1-M	Norwegian Climate Centre

Table2. Analysis target area

No	Identifier	Country of Region	No	Identifier	Country of Region
1	AUS	Australia	20	URY	Uruguay
2	CHN	China	21	XSM	Rest of South America
3	JPN	Japan	22	XCA	Rest of Central America
4	KOR	Korea Republic of	23	FRA	France
5	IDN	Indonesia	24	DEU	Germany
6	PHL	Philippines	25	GBR	United Kingdom
7	THA	Thailand	26	XEF	Rest of EFTA
8	VNM	Viet Nam	27	ROU	Romania
9	BGD	Bangladesh	28	RUS	Russian Federation
10	IND	India	29	UKR	Ukraine
11	PAK	Pakistan	30	XER	Rest of Europe
12	XAS	Rest of ASIA	31	IRN	Iran Islamic Republic of
13	CAN	Canada	32	TUR	Turkey
14	USA	United States of America	33	XWS	Rest of Western Asia
15	MEX	Mexico	34	EGY	Egypt
16	ARG	Argentina	35	XAC	South Central Africa
17	BOL	Bolivia	36	XEC	Rest of Eastern Africa
18	BRA	Brazil	37	ZAF	South Africa
19	PRY	Paraguay	38	XTW	Rest of the World

(Note) The ones beginning with X indicate that the region is an integrated country considering geographical proximity.

2.2. Quantification index of systemic risk from the viewpoint of yield fluctuation

In order to analyze the synchronized movement of annual yield fluctuations for the 4 target crops, yield data are classified into period 1 (1961-2014: actual data), period 2 (2015-2050: mid-term forecast data) and period 3 (2051-2100, long-term forecast data), and the correlation coefficients (R) of the yield fluctuation among countries and crops in each period are measured. Since the actual data for 1961-2014 includes influences other than climatic factors such as increases in fertilizer and pesticide inputs in the meantime, the yield fluctuation ($\widetilde{YA}$) removing the trend component is calculated by the following equation.

$$\widetilde{YA}_{i,r,t} = YA_{i,r,t} / (a_{i,r} + b_{i,r} \cdot t) \qquad (1)$$

Here, i, r, and t represent the four crop categories, countries and year. YA is the actual yield. a and b are respectively the intercept and slope, when the yields by crops and countries are regressed to the trend (t). The predicted yield by crop model is used as it is. The predicted yields for 2015 and beyond by the crop model are estimated by inputting only the climatic factors for each year into the crop model, so the predicted yields are considered as excluding the effects of future fertilizers, changes in agricultural chemical inputs and technological progress.

If the correlation coefficient for each period is stable regardless of the period, there is covariation in the yield of the four crops and countries. To quantify the stability of this correlation coefficient, the following indicators are calculated between periods 1 and 2, and between periods 2 and 3.

$$CR = \begin{cases} R^{tm} / R^{tm-1} & (R^{tm} \neq 0 \; and \; R^{tm-1} \neq 0) \\ 0 & (R^{tm} = 0 \; or \; R^{tm-1} = 0) \end{cases} \qquad (2)$$

Here, tm and tm-1 are the target period and the previous period, respectively. When the data of period 2 is targeted, tm-1 is filled with data of period 1. In addition, a statistically uncorrelated test on R is performed, and the ratio of R between two periods is calculated only when both tm and tm-1 are significantly different from zero at the 5% level. CR is set as zero if the correlation coefficient can be regarded as uncorrelated.

If CR is positive, the signs of the correlation coefficients in the two periods coincide, and if CR exceeds 1, it indicates that the correlation is stronger in the latter period. Therefore, the synchronicity of the yield fluctuation can be verified by looking at the number of combinations of countries in which the value of CR is positive and exceeds 1 among the combinations of correlation coefficients of each country.

2.3. World CGE model for analysis

In order to quantify the magnitude of systemic risk, which can be shown by the effect of synchronicity of the yield fluctuations of the four main crops over the fluctuation of agricultural prices in the world, a global CGE model that can simultaneously analyze production volume and price can be used. The model used is that presented by Lanz and Ruthreford (2016). Figure 1 shows the production structure of their model.

Furthermore, with regard to imports, based on Armington's assumptions, the structure shown in Figure 4 is such that imports from each country are integrated under a substitution elasticity.

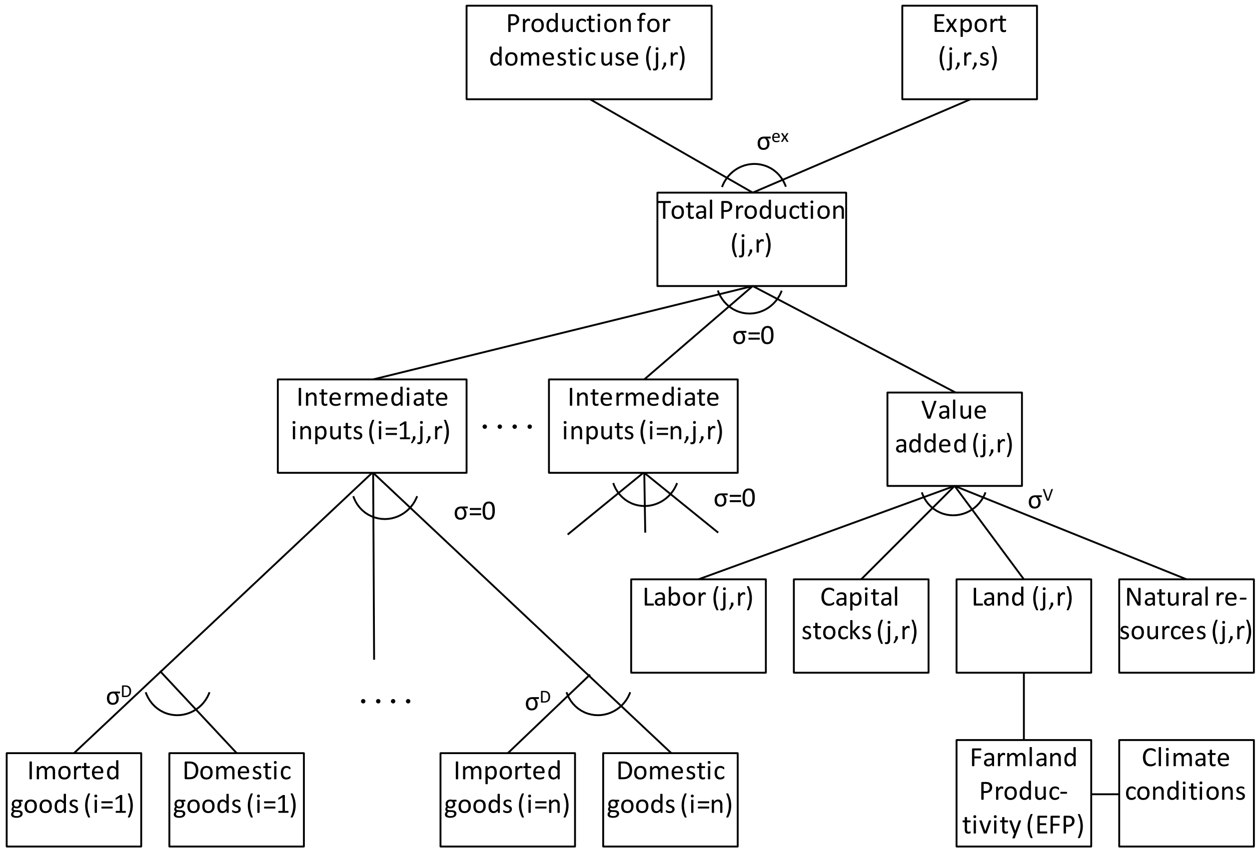


Figure 1. Structure of world CGE model

(Note) Here, i and j show industrial sectors, and r is a subscript that represents a country / region. labor and capital stocks are production factors which can be used by all sectors, and land and natural resources are sector-specific factors mainly used in primary industries. σ represents the elasticity of substitution. $\sigma = 0$ means Leontief type production function for intermediate inputs (i = 1 to n) and bundle of added value. $\sigma \neq 0$ means CES type production function for bundle of added value and domestic goods / imported goods.

The consumption structure is a hierarchical structure formulated by LES (Linear Expenditure System) as shown in Fig. 2. The public consumption and investment demand are also defined by the hierarchical structure as shown in Fig. 2.

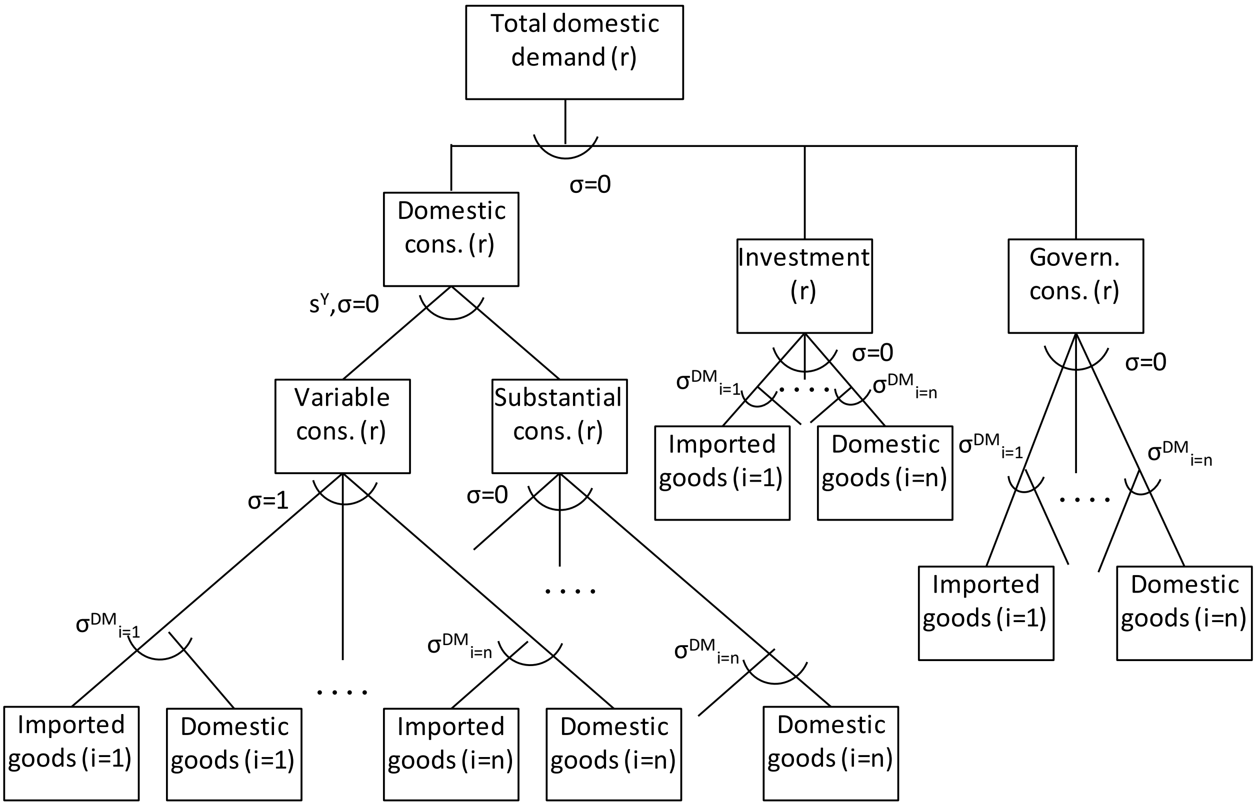


Figure 2. CES hierarchy in the consumer sector

(Note) Here, the subscripts on the right shoulder of the price (p), DD and SD, represent variable consumption and basic consumption. σ is a substitution elasticity. tpd and tpi represent the consumption tax rate (domestic goods) and the consumption tax rate (imported goods), respectively.

Figure 3 shows import choice of each country. The choice among imports from different trading partners is based on Armington's idea of regionally differentiated products. Transportation services enter on a proportional basis with imports from different countries, reflecting differences in unit transportation margins across different goods and trading partners.

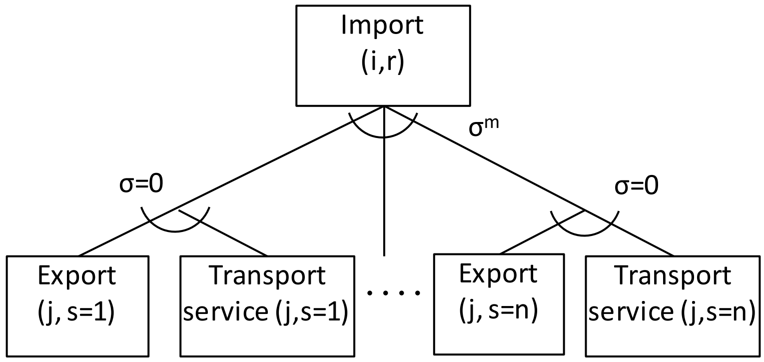


Figure 3. Armington aggregation of traded goods

The calibration of model parameters is based on the GTAP 9 database (Purdue University, Global Trade Analysis Project), and data were integrated into 38 regions as in the case of quantification of systemic risk (Table 1). Industrial sectors in data are also integrated into 12 sectors (Table 2) to solve the model easily. The substitution elasticity for production, consumption, government consumption and trade are the same as those in the GTAP 9 database, and the Frisch parameter in consumption is as well.

Table 2. Analysis target industries

No	Identifier	Industrial sectors	No	Identifier	Industrial sectors
1	PDR	Paddy rice	7	MIN	Minnig & forestry nec
2	WHT	Wheat	8	OFD	Food products nec
3	GRO	Cereal grains nec	9	VOL	Vegetable oils and fats
4	OCR	Crops nec	10	PCR	Processed rice
5	OSD	Oil seeds	11	MAN	Manufacturing
6	OAP	Animal products nec	12	SEV	Service

2.3. Simulation method

The following cases are assumed to quantify the degree of systemic risk related to agricultural trade.

Case 1 (business as usual, BAU, case under climate change): The current trade structure (no change in import duties) is maintained in consideration of future yield fluctuations of major crops under climate change. The impact of future yield fluctuations is predicted by the 5 GCMs under the conditions of RCP (Representative Carbon Pathway) 8.5 for four crops of rice, wheat, soybean, and corn. Such yield fluctuations are then assumed to correspond to changes in land production efficiency in the production function of the CGE model as follows[1].

$$EFP_{i,r,t} = \left(Yield_{i,r,t} / Yield_{i,r,2011} \right) \qquad (3)\ .$$

Here, i is the kinds of crops and corresponds to the industrial sectors relating to agriculture in the CGE model. t is the year, and Yield is the predicted yield by the crop model. The RCP 8.5 projection of the future climate assumed is the case where the concentration of greenhouse gases in the air is highest and the world's average temperature becomes highest.

Case 2 (Case of trade liberalization of agricultural products under climate change): Considering future yield fluctuations of major crops under climate change, import tariffs on agricultural products (PDR, WHT, GRO, OCR, OSD, OAP, OFD, VOL, PCR) are set as 0 to show a progress of trade liberalization. The impact of future climate change is assumed as in Case 1.

Case 3 (BAU under random fluctuations): The fluctuations of future agricultural production is assumed to occur randomly, and the current trade structure is maintained (no change in import tariffs and export subsidies). Although the impact of future climate change will affect agricultural production, it is assumed that the impact is unpredictable and will affect production as a random shock. Random shocks are generated by random numbers that follow a lognormal distribution. The

---

[1] It is assumed that if the success rate of land production improves due to the increase in counter-revenue, the same effect as the increase in agricultural land input will be produced. That is, in the agriculture sector, the following CES type production function is assumed.

$$YV_{i,r,t} = \left(\gamma_{i,r} (EFP_{i,r,t} \bullet A_{i,r})^{\sigma} + (1-\gamma_{i,r}) KL_{i,r}{}^{\sigma} \right)^{1/\sigma} \qquad (2)$$

Here, A is land input, KL is the combined input of capital and labor, γ is the distribution ratio to farmland, and σ is the alternative elasticity between A and KL.

standard deviation given at the time of random number generation is that of the actual yields of 1961-2014 for the four main crops and for each country, and is calculated from the data (YA) in which the trend component is excluded by the method explained above.

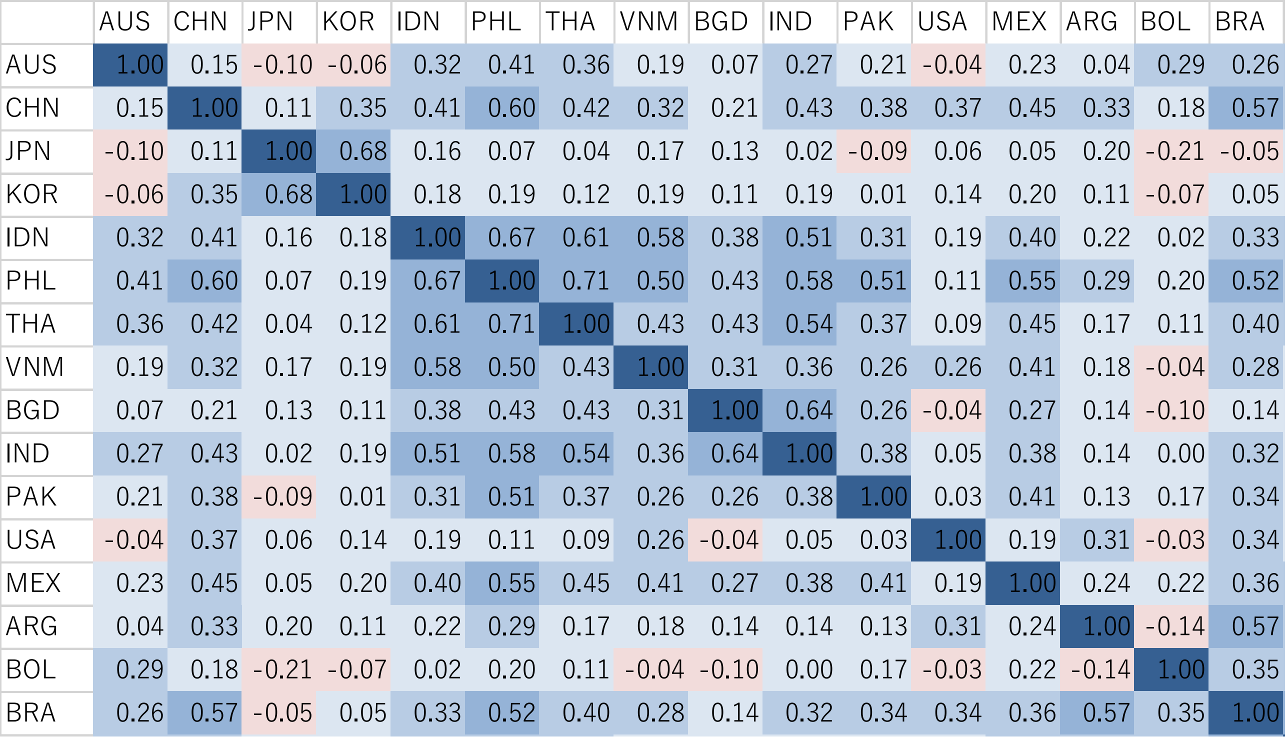
Case 4 (Agricultural product trade liberalization case under random fluctuations): Import tariffs on agricultural products are set as zero for trade liberalization, and the fluctuations in the future agricultural production randomly occur. The assumption that the impact of future climate change randomly affects agricultural production is the same as Case 3. In addition, trade of agricultural products increases by reducing the tariffs of the agricultural products in each country.

3. Results

3.1. Potential of systemic risks in global grain production

Figure 4 shows the correlation coefficient matrix between countries based on the predicted yield for the period 3 (2051 to 2100) of the simulation for paddy, of which 16 countries are represented by a heat map. Due to a space limitation, only 16 major countries were extracted. There were many combinations of countries where the correlation coefficient was statistically significant, and there were also combinations other than neighboring countries. For example, not only the correlation between the Philippines and Indonesia, but also the correlation between the Philippines and Mexico were high. This suggests that during this period, similar climatic conditions are occurring between geographically separated Philippine and Mexico.

In addition, there were many combinations of countries that had a positive correlation rather than a negative correlation. In the result of analyzing the actual yield of each crop by correlation (Saito, 2017), the correlation coefficients were not so high, unlike Fig. 4. Fig. 4 used the yield prediction of the crop model, so the fluctuations due to other factors than climatic conditions were removed, but the actual fluctuations calculated in the previous study were influenced by other factors as well as climate factors. From this reason, the correlations directly calculated from actual yields became low.

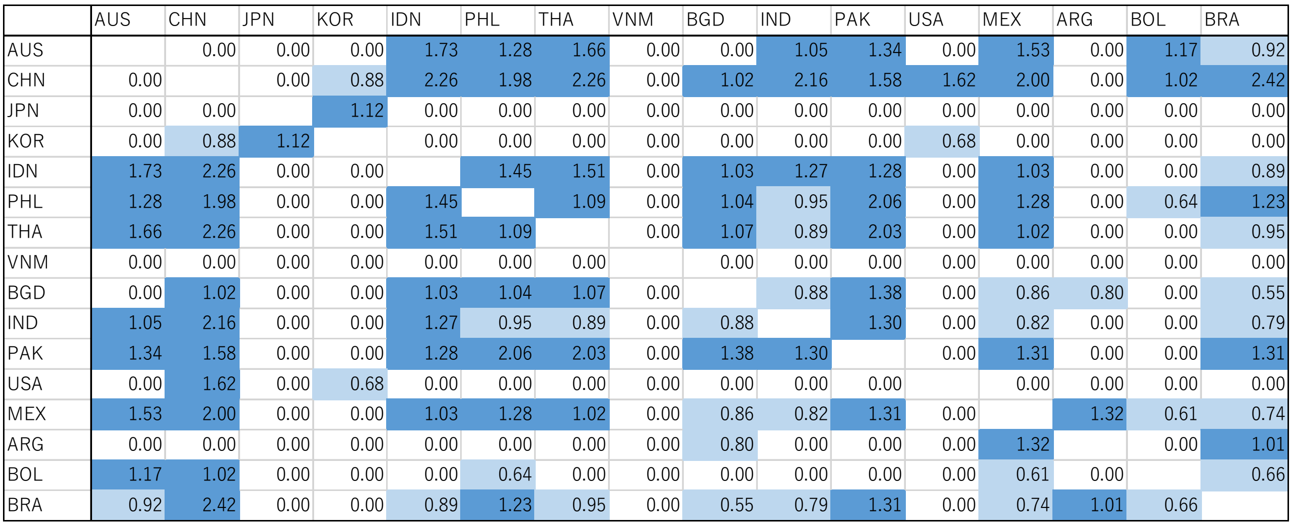


	AUS	CHN	JPN	KOR	IDN	PHL	THA	VNM	BGD	IND	PAK	USA	MEX	ARG	BOL	BRA
AUS	1.00	0.15	-0.10	-0.06	0.32	0.41	0.36	0.19	0.07	0.27	0.21	-0.04	0.23	0.04	0.29	0.26
CHN	0.15	1.00	0.11	0.35	0.41	0.60	0.42	0.32	0.21	0.43	0.38	0.37	0.45	0.33	0.18	0.57
JPN	-0.10	0.11	1.00	0.68	0.16	0.07	0.04	0.17	0.13	0.02	-0.09	0.06	0.05	0.20	-0.21	-0.05
KOR	-0.06	0.35	0.68	1.00	0.18	0.19	0.12	0.19	0.11	0.19	0.01	0.14	0.20	0.11	-0.07	0.05
IDN	0.32	0.41	0.16	0.18	1.00	0.67	0.61	0.58	0.38	0.51	0.31	0.19	0.40	0.22	0.02	0.33
PHL	0.41	0.60	0.07	0.19	0.67	1.00	0.71	0.50	0.43	0.58	0.51	0.11	0.55	0.29	0.20	0.52
THA	0.36	0.42	0.04	0.12	0.61	0.71	1.00	0.43	0.43	0.54	0.37	0.09	0.45	0.17	0.11	0.40
VNM	0.19	0.32	0.17	0.19	0.58	0.50	0.43	1.00	0.31	0.36	0.26	0.26	0.41	0.18	-0.04	0.28
BGD	0.07	0.21	0.13	0.11	0.38	0.43	0.43	0.31	1.00	0.64	0.26	-0.04	0.27	0.14	-0.10	0.14
IND	0.27	0.43	0.02	0.19	0.51	0.58	0.54	0.36	0.64	1.00	0.38	0.05	0.38	0.14	0.00	0.32
PAK	0.21	0.38	-0.09	0.01	0.31	0.51	0.37	0.26	0.26	0.38	1.00	0.03	0.41	0.13	0.17	0.34
USA	-0.04	0.37	0.06	0.14	0.19	0.11	0.09	0.26	-0.04	0.05	0.03	1.00	0.19	0.31	-0.03	0.34
MEX	0.23	0.45	0.05	0.20	0.40	0.55	0.45	0.41	0.27	0.38	0.41	0.19	1.00	0.24	0.22	0.36
ARG	0.04	0.33	0.20	0.11	0.22	0.29	0.17	0.18	0.14	0.14	0.13	0.31	0.24	1.00	-0.14	0.57
BOL	0.29	0.18	-0.21	-0.07	0.02	0.20	0.11	-0.04	-0.10	0.00	0.17	-0.03	0.22	-0.14	1.00	0.35
BRA	0.26	0.57	-0.05	0.05	0.33	0.52	0.40	0.28	0.14	0.32	0.34	0.34	0.36	0.57	0.35	1.00

Fig. 4 Heat map of correlation coefficient matrix in rice cultivation (16 countries)

Figure 5 shows the robustness of the correlations between period 3 and period 2 using equation (2). As shown by the CR ratios between countries with significant correlations, such as the Philippines and Indonesia and the Philippines and Mexico listed above, there are many combinations where the correlations are significant in both periods.

Table 3 summarized the robustness of the correlation coefficients between three periods including period 1 using the same CR ratio for four crops. The CR ratios of countries with positive number (CR>0) showing high correlation robustness between the two periods were 7-20% in periods 1 and 2, and 16-41% in periods 2 and 3. Furthermore, in the periods 2 and 3, the number of combinations in which the CR ratios were positive and exceeded 1 was greater than that in the periods 1 and 2. Among four crops, Rice and Soybean had a higher number of CR ratios than the other two crops, showing that many countries continue the strong correlation between both periods.



	AUS	CHN	JPN	KOR	IDN	PHL	THA	VNM	BGD	IND	PAK	USA	MEX	ARG	BOL	BRA
AUS		0.00	0.00	0.00	1.73	1.28	1.66	0.00	0.00	1.05	1.34	0.00	1.53	0.00	1.17	0.92
CHN	0.00		0.00	0.88	2.26	1.98	2.26	0.00	1.02	2.16	1.58	1.62	2.00	0.00	1.02	2.42
JPN	0.00	0.00		1.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KOR	0.00	0.88	1.12		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00
IDN	1.73	2.26	0.00	0.00		1.45	1.51	0.00	1.03	1.27	1.28	0.00	1.03	0.00	0.00	0.89
PHL	1.28	1.98	0.00	0.00	1.45		1.09	0.00	1.04	0.95	2.06	0.00	1.28	0.00	0.64	1.23
THA	1.66	2.26	0.00	0.00	1.51	1.09		0.00	1.07	0.89	2.03	0.00	1.02	0.00	0.00	0.95
VNM	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BGD	0.00	1.02	0.00	0.00	1.03	1.04	1.07	0.00		0.88	1.38	0.00	0.86	0.80	0.00	0.55
IND	1.05	2.16	0.00	0.00	1.27	0.95	0.89	0.00	0.88		1.30	0.00	0.82	0.00	0.00	0.79
PAK	1.34	1.58	0.00	0.00	1.28	2.06	2.03	0.00	1.38	1.30		0.00	1.31	0.00	0.00	1.31
USA	0.00	1.62	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
MEX	1.53	2.00	0.00	0.00	1.03	1.28	1.02	0.00	0.86	0.82	1.31	0.00		1.32	0.61	0.74
ARG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	1.32		0.00	1.01
BOL	1.17	1.02	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00		0.66
BRA	0.92	2.42	0.00	0.00	0.89	1.23	0.95	0.00	0.55	0.79	1.31	0.00	0.74	1.01	0.66	

Fig. 5 Robustness of correlation (CR value) between period 2 (2015-2050) and period 3 (2051-2100)

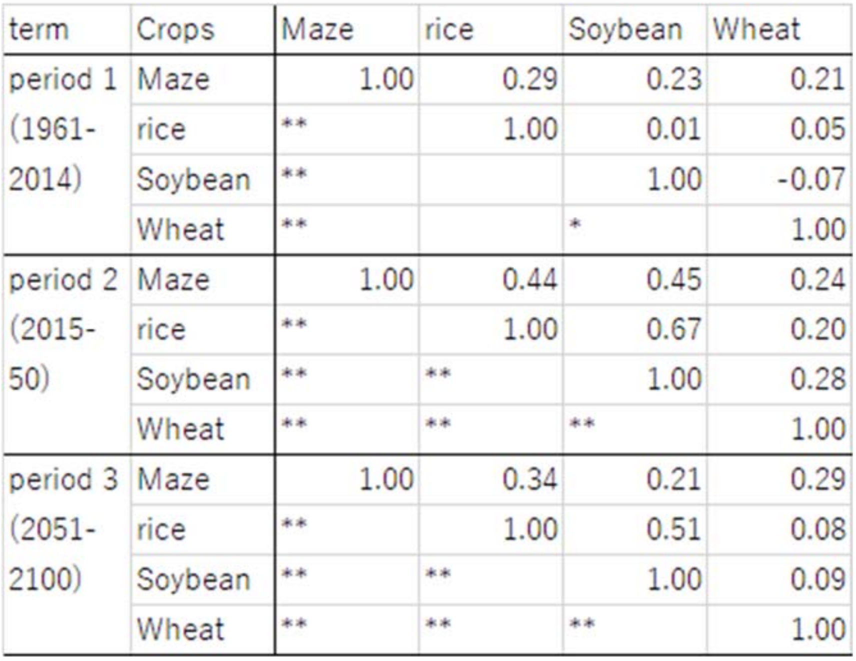
Table 3. Robustness of correlation between two periods (Number of combinations between countries by CR value)

Item		1961－2014：2007－2050		2007－2050：2051－2100	
Maze	Whole	406		630	
	CR≠0	110	0.271	144	0.229
	CR>0	68	0.167	124	0.197
	R>0 ⇒ R>0	55	0.135	104	0.165
	CR≧1	3	0.007	78	0.124
Rice	Whole	496		595	
	CR≠0	166	0.335	250	0.420
	CR>0	96	0.194	246	0.413
	R>0 ⇒ R>0	90	0.181	239	0.402
	CR≧1	17	0.034	150	0.252
Soybean	Whole	300		666	
	CR≠0	35	0.117	260	0.390
	CR>0	20	0.067	244	0.366
	R>0 ⇒ R>0	18	0.060	239	0.359
	CR≧1	6	0.020	205	0.308
Wheat	Whole	406		630	
	CR≠0	41	0.101	105	0.167
	CR>0	27	0.067	102	0.162
	R>0 ⇒ R>0	19	0.047	78	0.124
	CR≧1	9	0.022	33	0.052

Table 4 shows the correlation coefficient matrix between the four crops for each period using the pooled data with the annual yields predicted from five GCMs in 38 countries. The effects of climate change are similar for each crop within the same country regardless of kinds of GCMs. In other words, when one of the four crops become bad harvest, other crops tend to become bad harvest, and especially such tendency is strong among rice and soybeans.

Summarizing the results in Figs. 5, 6, Tables 3, and Table 4, there is a risk of systemic risk that is caused by The simultaneous global bad harvest and too good harvest. Also, such tendency is facilitated by future climate change.

Table 4 Correlation coefficient between crops



term	Crops	Maze	rice	Soybean	Wheat
period 1 (1961-2014)	Maze	1.00	0.29	0.23	0.21
	rice	**	1.00	0.01	0.05
	Soybean	**		1.00	-0.07
	Wheat	**		*	1.00
period 2 (2015-50)	Maze	1.00	0.44	0.45	0.24
	rice	**	1.00	0.67	0.20
	Soybean	**	**	1.00	0.28
	Wheat	**	**	**	1.00
period 3 (2051-2100)	Maze	1.00	0.34	0.21	0.29
	rice	**	1.00	0.51	0.08
	Soybean	**	**	1.00	0.09
	Wheat	**	**	**	1.00

3.2. Impacts of systemic risk on world agricultural price fluctuations

Table 5 shows the coefficient of variation (standard deviation / average) in efficiency of farmland productivity (EFP) during the period 3 (2051-2100) in Case 1 for 15 major countries picked up, which was calculated based on the yield estimated by the crop model with 5 GCMs. 7th to 9th column of this table also shows the ratio of which the coefficient of variation in Case 1 was divided by that in Case 3 which assumed random occurrence of yield fluctuation.

When comparing by crop, the fluctuation of EFP increases in the order of soybean> rice> maize> wheat. In all crops, the variation coefficient is larger in Case 1, where the yield is predicted using a crop model, than that in Case 3 of randomly changing. However, in some crops and countries, such as rice in Vietnam and wheat in India, the US, Canada, Germany and Russia, the coefficient of variations are smaller in Case 1 than Case 3.

However, there are points to note. In case 3 of random fluctuation, random numbers were generated based only on the standard deviation of real crop yield in 1961-2014. In contrast, Case 1, which used the results of the crop model, calculated the coefficient of variation, including the effect that the yield itself increased or decreased due to future climate change. Therefore, the coefficient of variation tends to be larger in the crop model results in countries and crops where future increases in average temperature raise global grain yields in every country.

Table 5 Future changes in EFP in 15 major countries

	CV of EFP (Crop model case)				Crop model case / Random deviation case			
	Paddy	Wheat	Soybean	Maze	Paddy	Wheat	Soybean	Maze
Japan	0.053	0.107	0.111		0.863	0.880	1.044	-
China	0.115	0.120	0.141	0.108	1.577	1.392	1.559	1.485
Indonesia	0.147		0.055	0.186	1.748	-	1.140	1.688
Thailand	0.099	0.215	0.304	0.355	1.210	1.612	1.821	2.804
Viet Nam	0.225	0.152	0.283	0.211	1.234	3.349	1.864	2.523
India	0.078	0.075	0.305	0.255	0.997	1.099	1.534	1.921
USA	0.047	0.094	0.066	0.252	0.874	1.397	0.999	2.857
Canada		0.183	0.148	0.123	-	1.280	1.316	1.349
Brazil	0.242	0.359	0.131	0.240	1.450	1.480	1.182	1.987
Argentina	0.167	0.192	0.207	0.260	1.252	1.434	1.406	2.322
France	0.834	0.121	0.787	0.159	2.798	1.104	2.047	1.903
Germany		0.066	0.471	0.100	-	0.947	1.314	1.238
Russia	0.247	0.143	0.292	0.204	1.319	1.230	1.418	1.414
Egypt	0.144	0.115	0.393	0.249	1.296	1.147	1.340	2.431
South Africa	0.155	0.687	0.470	0.286	1.378	1.376	2.046	1.969

Tables 6 and 7 summarized the simulation results of changes in agricultural added value and agricultural price during the period 3 in Case 1 (using crop model estimation) and Case 3 (generating random fluctuation). The following points can be seen in these tables.

First, when comparing Case 1 (results of crop models) and Case 3 (results assuming random fluctuations), the former coefficient of variation is larger in both agricultural value added and agricultural prices. On average across the world, fluctuations in the crop model case are 22% higher for agricultural value added and 84% higher for agricultural prices than random fluctuation case.

In other words, by taking into account the correlation among crops and among countries, the fluctuation range of agricultural added value and agricultural prices becomes large. As mentioned earlier, in actual yield fluctuations, the correlation among crops and among countries becomes invisible due to effects of other factors. Therefore, the risk deduced from past changes alone is smaller than the systemic risk considering the correlation among crops and among countries.

Second, when the values of maximum and minimum were compared in each country in Case 1, for agricultural added value the degrees of difference between 1.0 and maximum or minimum are about the same. However, the agricultural price is more likely to deviate from 1 in maximum values, suggesting that in many countries agricultural prices will more increase in the future due to climate change.

Third, in terms of agricultural added value, fluctuations increased in agricultural export countries such as Argentina, Egypt, Paraguay and Uruguay, although last 2 countries were not included in the table. As for agricultural prices, the price fluctuation in Egypt has increased, and it has been 2.26 times at the maximum and 0.89 times at the minimum compared to 2011. In other countries, the agricultural prices in Turkey and Romania increased. Egypt and Turkey listed here are countries with large imports of wheat. On the other hand, in India and Bangladesh, the agricultural prices decreased more than other countries due to climate change. In Japan, both agricultural added value and agricultural prices are less variable than in other countries. This is thought to be due to the fact that Japan imports most of the agricultural products from the US and Australia, and the fluctuations associated with climate change are small in these export countries.

Table 6. Changes in agricultural added value during the period 3 (2051-2100)

	Case 1			Case 3	Ratio (a)/(b)
	Max	Min	CV (a)	CV (Random) (b)	
Japan	1.020	0.988	0.006	0.002	2.76
China	1.067	0.966	0.021	0.005	4.57
Indonesia	1.074	0.957	0.025	0.007	3.48
Thailand	1.097	0.960	0.022	0.006	3.64
Viet Nam	1.089	0.953	0.026	0.006	4.51
India	1.041	0.970	0.014	0.004	3.76
U.S.A	1.143	0.957	0.030	0.004	8.39
Canada	1.234	0.941	0.044	0.007	5.89
Brazil	1.091	0.956	0.026	0.004	7.10
Argentina	1.112	0.917	0.039	0.015	2.64
France	1.037	0.970	0.012	0.004	3.26
Germany	1.044	0.979	0.010	0.002	4.31
Russia	1.044	0.975	0.013	0.005	2.64
Egypt	1.058	0.944	0.015	0.005	3.21
South Africa	1.099	0.969	0.021	0.003	6.21

Table 7 Changes in prices of agriculture and food products during the period 3 (2051-2100)

	Case 1			Case 3	Ratio (a)/(b)
	Max	Min	CV (a)	CV (Random) (b)	
Japan	1.052	0.984	0.010	0.003	3.90
China	1.107	0.913	0.040	0.011	3.62
Indonesia	1.170	0.907	0.058	0.010	5.62
Thailand	1.445	0.899	0.070	0.007	9.97
Viet Nam	1.143	0.932	0.039	0.007	5.29
India	1.246	0.852	0.084	0.028	2.99
U.S.A	1.245	0.953	0.039	0.005	8.42
Canada	1.077	0.974	0.016	0.002	6.66
Brazil	1.080	0.950	0.026	0.007	3.94
Argentina	1.066	0.963	0.021	0.004	4.90
France	1.146	0.959	0.026	0.003	7.56
Germany	1.081	0.974	0.018	0.003	6.00
Russia	1.102	0.977	0.017	0.003	5.09
Egypt	2.359	0.902	0.178	0.012	14.36
South Africa	1.139	0.954	0.035	0.005	7.32

3.3. Trade liberalization and systemic risk under climate change

Table 8 shows the changes in net export value (export value-import value) when the tariff rate on products of agricultural and food sectors is zero. Case 1 and Case 2 are cases where yield fluctuations among crops and among countries are taken into account by the crop model, and Case 3 and Case 4 are cases where random fluctuations are assumed.

Although not included in this table, the net export value in Table 7 divided by the net export value in 2011 exceeded 1 in most countries (38 countries / 24 countries) in both Case 1 and Case 2, showing that imports increase at import countries and exports increase at export countries due to climate change. In other words, the amount of trade tends to increase due to climate change regardless of whether or not trade liberalization occurs.

Next, regarding the impact of trade liberalization due to the reduction of agricultural tariffs, the trade liberalization shown by Case 2 and Case 4 increased imports in Japan and China, and increased exports in food export countries such as the United States, Brazil, Indonesia, Thailand, and Vietnam. However, the effects of trade liberalization tended to be similar whether or not taking into account the correlation among crops and among countries due to climate change.

Table 8. Changes in net exports due to reductions in tariffs on agricultural products (average amount during the estimation period)

($ 1 billion / year)

	Crop model			Randum deviation			Ratio (d)/(f)
	Case 1 (a)	Case 2 (c)	Case 2/1 (d)=(c)/(a)	Case 3 (b)	Case 4 (e)	Case 4/3 (f)=(e)/(b)	
Japan	-68	-104	1.53	-71	-108	1.53	1.00
China	-63	-70	1.10	-64	-69	1.08	1.01
Indonesia	8	14	1.86	8	16	1.90	0.98
Thailand	17	20	1.17	20	24	1.19	0.98
Viet Nam	2	2	0.93	3	3	1.08	0.86
India	10	-6	-0.55	15	-3	-0.23	2.38
U.S.A	23	46	1.97	32	58	1.82	1.08
Canada	17	14	0.80	13	10	0.74	1.08
Brazil	71	88	1.24	67	85	1.27	0.98
Argentina	38	40	1.07	40	43	1.07	1.00
France	6	11	1.77	7	12	1.65	1.07
Germany	-17	-13	0.77	-18	-15	0.82	0.94
Russia	-22	-36	1.63	-24	-39	1.60	1.02
Egypt	-14	-17	1.25	-13	-17	1.25	1.00
South Africa	8	8	1.01	8	8	1.01	1.01

Tables 9 and 10 show changes in the coefficient of variation in agricultural added value and agricultural prices due to trade liberalization in agricultural and food sector. Column (d) in these tables is about the results using the crop model, and compares Case 2 with Case 1 shown in Tables 5 and 6. Column (f) is about random fluctuation simulation, and compares Case 4 with Case 3 shown in Tables 5 and 6.

In many countries, both the agricultural added value and the price increased due to trade liberalization. In some countries, however, trade liberalization has reduced the coefficient of variation, making it less risky. In Japan, the coefficient of variation became smaller as a result of trade liberalization. On the other hand, in India, the coefficient of variation doubled in terms of added value, and the risk increased. However, the coefficient of variation of agricultural prices in India was not so large due to trade liberalization. It is inferred that such differences among countries, or differences in production value and price, are caused by differences in how much they depend on imported agricultural products and on which crops they depend on for staple foods. However, it is difficult to specify the reasons in general.

Table 9. Changes in CV of added value in agricultural and food sector due to trade liberalization

	Crop model		Randum deviation		Ratio (d)/(f)
	Case 2 (c)	Case 2/1 (d)=(c)/(a)	Case 4 (e)	Case 4/3 (f)=(e)/(b)	
Japan	0.008	1.246	0.001	0.458	2.72
China	0.020	0.975	0.004	0.951	1.02
Indonesia	0.023	0.923	0.008	1.146	0.81
Thailand	0.021	0.961	0.009	1.597	0.60
Viet Nam	0.027	1.027	0.012	2.023	0.51
India	0.015	1.028	0.003	0.869	1.18
U.S.A	0.029	0.961	0.004	1.021	0.94
Canada	0.049	1.115	0.010	1.324	0.84
Brazil	0.024	0.936	0.003	0.962	0.97
Argentina	0.037	0.949	0.013	0.907	1.05
France	0.013	1.132	0.004	1.093	1.04
Germany	0.012	1.272	0.003	1.230	1.03
Russia	0.017	1.367	0.007	1.562	0.88
Egypt	0.015	0.985	0.005	0.977	1.01
South Africa	0.022	1.063	0.004	1.106	0.96

Table 10. Changes in CV of agriculture and food products' prices due to trade liberalization

	Crop model		Randum deviation		Ratio (d)/(f)
	Case 2 (c)	Case 2/1 (d)=(c)/(a)	Case 4 (e)	Case 4/3 (f)=(e)/(b)	
Japan	0.009	0.885	0.001	0.474	1.87
China	0.036	0.913	0.010	0.875	1.04
Indonesia	0.057	0.985	0.010	0.976	1.01
Thailand	0.074	1.048	0.006	0.798	1.31
Viet Nam	0.040	1.027	0.007	0.945	1.09
India	0.064	0.761	0.022	0.773	0.98
U.S.A	0.041	1.049	0.005	1.076	0.98
Canada	0.013	0.853	0.002	0.831	1.03
Brazil	0.027	1.022	0.007	1.032	0.99
Argentina	0.022	1.028	0.005	1.076	0.96
France	0.027	1.042	0.004	1.023	1.02
Germany	0.019	1.020	0.003	1.072	0.95
Russia	0.012	0.716	0.002	0.726	0.99
Egypt	0.127	0.710	0.009	0.716	0.99
South Africa	0.033	0.953	0.004	0.930	1.02

4. Conclusion and policy implications

Yield fluctuations in rice, wheat, soybean, and corn have a correlation among countries, as well as among crops. Thus, because of such synchronicity of harvest changes, future climate change may increase systemic risk to global agricultural production and prices. This study analyzed such systemic risk by using computable general equilibrium (CGE) model associated with future prediction results by the global climate model (GCM) and crop model. The simulation results suggests the following points.

First, for rice where the synergy of yield fluctuations is biggest, the yield synergy effect becomes significant among countries with more than 40%. Second, this synchronicity of yields increases fluctuations in agricultural production and agricultural price by 22% and 84%, respectively. Third, although trade liberalization can alleviate the vulnerability of agricultural production under climate change, in countries with large imports of agricultural products, such mitigation effect on price fluctuation by trade liberalization declines due to systemic risk. For example, in Japan, fluctuations in agricultural prices increase by about 7% due to worldwide synchronicity of yield changes as compared to the trade liberalization case with no systemic risk.

Therefore, by taking into accounts the systemic risk under future climate change, it is necessary to examine the true effects of agricultural trade policies and prepare countermeasures in advance.

References

Lanz B, Rutherford FT (2016) “GTAPINGAMS, version 9: Multiregional and small open economy models with alternative demand systems,” University of Neuchatel, Institute of Economic Research IRENE, Working paper 16-08.

Sakurai, G., Iizumi, T., Nishimori, M., and Yokozawa, M. (2014) How much has the increase in atmospheric CO2 directly affected past soybean production?, Scientific Reports 4(4978) 1-5

Tanaka T, Hosoe N (2011) Does agricultural trade liberalization increase risks of supply-side uncertainty?: Effects of productivity shocks and export restrictions on welfare and food supply in Japan, Food Policy 36: 368–377

Tigchelaar M, Battisti DS, Naylor RL, Ray DK (2018) Future warming increases probability of globally synchronized maize production shocks. PNAS, 115(26): 6644-6649. (www.pnas.org/cgi/doi/10.1073/pnas.1718031115)